THE INSTITUTE OF PHYSICS
47 BELGRAVE SQUARE, LONDON, S.W.1.

BULLETIN

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The Bulletin is not intended for general circulation : your copy should not therefore be passed to a library.

APPOINTMENTS VACANT

The inclusion of particulars of a vacancy must not be taken to imply that the Institute necessarily approves of the terms offered or that might be offered. Candidates should satisfy themselves that these are satisfactory, and they may always refer to the Institute for advice.

Central Electricity Authority, Research Laboratories, Leatherhead, require: **Physicists.** Candidates should have a University degree or equivalent qualification in physics. Duties include research on problems associated with the generation and transmission of electricity and preference will be given to candidates with some experience of flame radiation, or temperature measurement, or particle mechanics, or X-ray diffraction. Salary within one of the following scales, according to qualifications and experience.

N.J.B. Grade 2, £925–£1,275 p.a.
N.J.B. Grade 3, £865–£1,075 p.a.
N.J.B. Grade 4, £675–£850 p.a.

General Assistant Engineers. Candidates should have a Higher National Certificate or equivalent qualification in electrical or mechanical engineering or physics. Duties include the maintenance of a wide range of specialized instruments. Salary N.J.B. Grade 5, £475–£650 p.a., according to qualifications and experience.

Applications, stating age, qualifications, experience, present position and salary to D. Moffat, Director of Establishments, Winsley Street, W.1, by 10th August. Quote Ref. AE/645.

Central Research Establishment, National Coal Board (at Isleworth, Middlesex) which is concerned with mining problems, invite applications for a superannuable appointment of a **Physicist** or **Mathematician** to form a group carrying out research on underground transport of coal. The work will be concerned initially with belt conveyors and includes measurements of stress set up in the belt plies under working loads and the study of relevant physical properties of belt materials which determine their optimum performance and long life.

Candidates should have a good honours degree in Physics, Mathematics or equivalent professional qualifications, proved research ability and preferably experience in strain measurements and/or mechanical properties of materials.

Appointment will be as a Scientist I (scale £1,150 × £40 to £1,350 followed by a range to £1,550 male), London Location Allowance of £82 at the minimum rising to £100 at a maximum is payable in addition.

Write, giving full particulars (in chronological order) of age, education, qualifications and experience (with dates) to National Coal Board, Establishments (Personnel), Hobart House, Grosvenor Place, London, S.W.1., marking envelope SS/34. Original testimonials should not be forwarded. Closing date 16th August, 1955.

Physicist or **Physical Chemist** required by the cast concrete industry to undertake research into the physical structure and properties of concrete at research laboratories of the Cement and Concrete Association, Wexham Springs, near Slough. Applicants should have Honours Degree and preferably be below 27 years of age, but if older with experience in allied fields including rheology a commensurately higher salary will be paid. Opportunities for obtaining higher degrees. Possible assistance in housing. Write with full particulars to Secretary, B.C.C.F., 105, Uxbridge Road, Ealing, W.5.

Medical Research Council has vacancies for **Physicists** to work on problems associated with the use of the medical cyclotron and linear accelerator. Some experience of research in nuclear or radiation physics will be an advantage. Salary according to age and experience, but probably within scale £715–£900. Applications to the Director, Radiotherapeutic Research Unit, Hammersmith Hospital, London, W.12.

Senior Experimental Officer (Electronics) required by the Research and Development Branch of the **United Kingdom Atomic Energy Authority** at Windscale, Sellafield, Cumberland, to take charge of a small section engaged on design and construction of various electronic equipment for the chemistry, metallurgy, engineering and physics laboratories. The range of work is extremely wide and interesting and provides considerable scope for initiative and ingenuity. Applicants must have at least a Higher School Certificate in science subjects, or equivalent qualifications, together with wide experience of the application of electronics. Possession of a Higher National Certificate or appropriate City and Guilds Certificates may be an advantage. Salary £1,090–£1,285 p.a. All new entrants under the age of 55 automatically join the Authority's contributory pension scheme. Suitably qualified persons are invited to send post-cards for application form to the Recruitment Officer, Industrial Group Headquarters, Risley, Warrington, Lancs., quoting reference 1,048

Middlesex County Council
Education Committee

Acton Technical College,
High Road, Acton, W.3.
Department of Physics and Mathematics

Research Studentship

Applications are invited from Honours Graduates in Physics for appointment to a Research Studentship in Physics tenable from 1st September, 1955. The value of the Studentship is £350 per annum.

Applications from candidates taking a degree this summer will be considered but a good knowledge of electronics will be an advantage.

The Studentship will be awarded in the first instance for one year but, subject to satisfactory progress, may be considered for renewal on an annual basis.

Application forms (stamped addressed foolscap envelope) from the Principal, to whom completed forms should be returned by August 24, 1955.

C. E. Gurr,
Secretary to the Education Committee.

The development of techniques and instruments for spectroscopic methods of analysis offers interesting and progressive employment to graduate physicists and engineers wishing to enter the scientific instrument industry. Applications for a post in N.W. London should be made to the Personnel Officer, **Hilger and Watts Ltd., Hilger Division,** 98 St. Pancras Way, N.W.1.

(*Continued on page iii*)

Electronic Valves. Applications are invited for the post of **Chief Valve Development Engineer** at laboratories on the outskirts of London. Applicants should possess an honours degree, having long experience in the valve industry, the ability to secure results and to work in close-co-operation with other laboratories and production establishments within the Group.

Only candidates with a first class record and of outstanding ability will be considered for this senior appointment.

Salary will be commensurate with experience and qualifications, and the post is pensionable.

Applications, which will be treated in the strictest confidence, should state age, and salary expected to Box No. AV.83, The Institute of Physics, 47 Belgrave Square, London, S.W.1.

"Shell" Research Limited require a young **physicist** or **physical chemist** with a good Honours Degree for training in both laboratory and field studies relating to bitumen development and the scientific aspects of roadmaking. Salary in line with qualifications and past experience. Write giving full details to the **Shell Petroleum Company,** Staff Department R/T/B, St. Helen's Court, Great St. Helen's, London, E.C.3.

The Mond Nickel Co. Ltd.
invites applications from
Metallurgists, Chemists and Physicists
for various Senior and Junior posts in
The Research Laboratories in Birmingham and London
and
The Development Division in London

The work is concerned with fundamental researches and short term investigations covering Ferrous and Non-Ferrous Materials and the subsequent development and application of these in a wide variety of industries.

The present posts relate to :—

(*a*) Nickel-base alloys
(*b*) Alloy Steels and Cast Irons
(*c*) High Temperature Materials
(*d*) Special Chemical Products
(*e*) Precious Metals

Apply stating age, qualifications, experience and salary required to the Manager, Development and Research Department, The Mond Nickel Co. Ltd., Millbank, London, S.W.1. Mark envelope "Confidential 0.1."

The College of Aeronautics

Applications are invited for two appointments of **Lecturer** or **Senior Lecturer** in the **Department of Aircraft Electrical Engineering.** The Department covers all aspects of electrical equipment for aircraft, including power systems, communications, radar and servo-mechanisms. Candidates should be graduates or otherwise professionally qualified and should have appreciable experience in one or more of these branches. Status on appointment will depend upon qualifications and experience, the salary being within the scales £850 × £50 – £1,200 for Lecturer and £1,200 × £50 – £1,600 for Senior Lecturer, with prospects of a higher category carrying a salary maximum of £1,850 in an exceptional case. Emoluments include superannuation under F.S.S.U. and family allowance. Further information may be obtained from the Recorder, The College of Aeronautics, Cranfield, Bletchley, Bucks, with whom applications, quoting not more than three referees, should be lodged by 15th August, 1955.

Manchester
College of Technology
(Faculty of Technology in the University of Manchester)
Appointment of
Lecturers in Physics

The Governing Body invites applications for two Lectureships in Physics in the College of Technology with the title and status of Lecturers in the University of Manchester.

The successful candidates will be required to take part in the teaching of the department which is almost entirely concerned with internal degrees af the Faculty, in Applied Physics and other subjects. They will also be allowed ample time for research, the main subjects at present being physical optics and X-ray diffraction. The department is shortly to move into new and enlarged quarters in the College extension.

Salary £650 per annum, rising by annual increments of £50 to £1,350 per annum. Commencing salary according to qualifications, Superannuation under the F.S.S.U. and family allowances.

Conditions of appointment and form of application may be obtained from the Registrar, College of Technology, Manchester 1. The last day for the receipt of application is Thursday, 1st September, 1955.

B. V. Bowden,
Principal of the College.

The newly formed **British Glass Industry Research Association** has vacancies for **Physicists** at its laboratories in Sheffield.

A good working knowledge of applied physics is essential, while the subsidiary interests can well range from rheology to mineralogy. Basic fundamental problems related to the structure of glass, as well as "day-by-day" trouble shooting problems are under investigation. F.S.S.U. benefits and facilities for further study for higher qualifications are available.

Applications, giving full details of age, experience, qualifications and salary, should be sent in confidence to : The Director of Research, British Glass Industry Research Association, Elmfield, Northumberland Road, Sheffield, 10.

Commonwealth of Australia
Department of Health

A vacancy exists for a **Senior Physicist** in the Commonwealth X-ray and Radium Laboratory, Melbourne. This laboratory is the national centre in radiological physics in Australia, and is responsible for the procurement and distribution of radio-isotopes used in medicine, industry and research.

Salary: £1688–1814 (Australian) per annum.

Duties : Supervise the Radium, Radon and Radio-isotopes Sections of the Laboratory ; and investigations, as directed, in these fields.

Qualifications : University degree in Science (preferably with honours), with a major in Physics. Considerable experience in radiation physics including use of radio-isotopes.

Fares : Fares, including those of wife and family, will be paid.

Applications stating full name, place, date and year of birth, marital status, nationality, present employment, details of qualifications and experience, war service (if any), together with copies of not more than four testimonials, to The Official Secretary, Australia House, Strand, London, W.C.2, by 20th August, 1955.

Commonwealth of Australia

Appointment of Physicist

The Division of Physics of the Commonwealth Scientific and Industrial Research Organization, Australia, is seeking a **physicist** (Senior Research Officer or Research Officer).

The Division of Physics is located at the National Standards Laboratory, Sydney, N.S.W.

The appointment is for experimental research in the Division's cryogenic group. The appointee will have considerable freedom of choice in his lines of research within the overall field of the study of the properties of materials at low temperatures. To date the main concern of the group in both its theoretical and experimental research has been the electrical and thermal conductivities of metals and alloys for the purpose of studying the processes which limit these transport phenomena. This work is now being extended to measurements of (*a*) magnetothermal conductivities of electrical conductors, (*b*) thermal conductivities of dielectric solids and (*c*) specific heats. The facilities of the group include a helium liquifier of the Collins type with which stocks of liquid helium are maintained, available for use at all times. A 15 kilogauss magnet is under construction. The ancillary services and technical assistance are good.

Initially the appointment will be for a period of three years but may be extended.

Applicants should possess a Ph.D. degree or equivalent in physics with experience in cryogenic research.

Salary on commencement will be determined according to qualifications and experience and will be within the range of Senior Research Officer £A1814–£A2078 p.a. or Research Officer £A1184–£1730 p.a. An appointee holding a Ph.D. degree will receive a salary of not less than £A1394 p.a.

Fares to Australia (including those of wife and family) will be paid also the return fares in cases where the appointee does not take up a permanent position at the expiry of his initial period. The appointment is conditional on a satisfactory medical examination and applicants offered permanent appointment will be eligible for superannuation benefits.

Applications, referring to Appointment No. 770/102, stating full name, place and date of birth, marital state, nationality, particulars of qualifications and experience, the names and addresses of two referees and enclosing copies of two testimonials should reach the undersigned not later than the 31st August, 1955.

W. Ives
Chief Scientific Liaison Officer
Australian Scientific Liaison Office,
Africa House, Kingsway, London, W.C.2.

The United Kingdom Atomic Energy Authority, Foulness, Essex requires **Assistant Experimental Officers**. (*a*) to undertake work on the strength of building structures. (*b*) to assist in the recording of blast pressure characteristics from explosions. The minimum qualification is H.S.C. (Science) or equivalent. For post (*a*) applicants should have had some experience in the fields of mechanical engineering or physics and for post (*b*) some electronic experience will be required.

Salary £310 p.a. (age 18)—£685 p.a. (Male). The successful applicant will be required to join the Authority's contributory superannuation scheme.

The Authority may be able to assist in the purchase of a house.

Requests for application forms by Post Card to Senior Recruitment Officer, A.W.R.E., Aldermaston, Berks. Quote reference 569/WGE 110.

British Thomson-Houston Co. Ltd. has a vacancy in its Research Laboratory at Rugby for a qualified **Physicist** to work with a team of chemists on the application of Mass Spectrometry to the study of solids, including semi-conducting materials. This work is just starting and offers interesting possibilities in expanding applications. Applicants are invited to submit details of their age and qualifications to the Director of Research, British Thomson-Houston Co. Ltd., Rugby, quoting Reference JJ.

British Thomson-Houston Co. Ltd. invites applications for posts in the Metallurgy Section of its Research Laboratory at Rugby. The work consists of research in physical metallurgy with particular reference to high temperature properties and strength of alloys. Applicants should be graduates or have high qualifications in Metallurgy, or Physics, and preferably be under 35. Apply, quoting reference OG, and stating age, qualifications and experience to the Director of Research, British Thomson-Houston Co. Ltd., Rugby.

A vacancy exists for an **X-ray crystallographer** to work as a member of a new and expanding group engaged in investigating fundamental behaviour and properties of alloys. The work initially involves the application of special X-ray techniques to the study of pre-precipitation phenomena. Some research experience is required but need not necessarily be in the particular field outlined above. The work is interesting and progressive, and provides an unusual opportunity for a man with initiative and enthusiasm to perform original research, which may be suitable for publication. The laboratories are situated in pleasant country surroundings and have recently been extended. The salary will be attractive and in accordance with age and experience. A pension scheme is in operation. Applications should be addressed to the Director of Research, **Aluminium Laboratories Limited,** Banbury, Oxon.

Manchester
College of Technology

(Faculty of Technology in the University of Manchester).

Appointment of
Assistant Lecturer in Physics

The Governing Body invites applications for an Assistant Lectureship in Physics in the College of Technology, with the title and status of Assistant Lecturer in the University of Manchester.

The successful candidates will be required to take part in the teaching of the department which is almost entirely concerned with internal degrees of the Faculty, in Applied Physics and other subjects. They will also be allowed ample time for research, the main subjects at present being physical optics and X-ray diffraction. The department is shortly to move into new and enlarged quarters in the College extension.

Salary: £550 per annum, rising by annual increments of £50 to £650: Superannuation under the F.S.S.U. and family allowances.

Conditions of appointment and form of application may be obtained from the Registrar, College of Technology, Manchester, 1. The last day for the receipt of application is Thursday, 1st September, 1955.

B. V. Bowden,
Principal of the College.

THE INSTITUTE OF PHYSICS

Vol. VI, No. 8 **BULLETIN** August, 1955

NOTICES TO MEMBERS

Availability of places for physics students

As was mentioned in the April *Bulletin*, the Board requested the Deputy Secretary some months ago to conduct an enquiry among universities and some of the principal technical colleges to obtain data concerning the places available for students wishing to read for qualifications in physics. A full report on the enquiry has now been approved by the Board and will be published in the September *Bulletin*. Accompanying it will be the comments of the Institute's Education Committee and its Membership and Examinations Committee which have met jointly to discuss the report. Reprints of the report and comments will also be available ; it is intended to circulate them widely among educational and other bodies likely to be interested.

Accommodation available

The Will of the late Mrs. Phillips provides for the tenancy and maintenance of a self-contained flat in Welling, Kent, to be within the gift of the Institute.

Any member (irrespective of age) who may be in need of this kind of assistance for a short or long period is therefore invited to make further enquiries of the Secretary of the Institute.

Geneva International Conference on Peaceful Uses of Atomic Energy

Members will know from the Press that the United Nations Organization has arranged a very large Conference on " Peaceful uses of atomic energy " which is being held in Geneva from August 8–20. Nearly 60 Governments accepted invitations to send representatives and in addition to these official delegations, many other observers and industrial representatives are being accommodated in public galleries and in some cases in other halls where the proceedings will be relayed on closed circuit. Admission for members of the public is by ticket issued by the Permanent U.N. Office in Geneva.

The proceedings include more than 1000 papers, many of which will be presented orally and discussed by the delegates. The proceedings will be published in full, and summaries of the whole Conference will be published in many technical and scientific periodicals in this country and abroad. In view of this and the fact that the Institute is itself holding a Conference in July next year on the "Physics of nuclear reactors," it has been decided not to cover the Conference in the Institute's own Journals.

Massachusetts Institute of Technology : Foreign Students' Project 1956

The Massachusetts Institute of Technology is offering a small number of scholarships to university graduates in science and technology, to enable them to attend the summer session of the Institute from June 4 to September 25, 1956.

Both men and women are eligible for these awards. Candidates must be British citizens under 28 years of age, in good health, who hold recognized university degrees in technical fields and have had at least two years' work in either industrial or academic research since graduating.

Application forms may be obtained after Monday, August 22, 1955, from The Cultural Affairs Officer, American Embassy, Room 302, 41 Grosvenor Square, London, W.1. No applications can be considered that are received at the Embassy after Friday, October 14, 1955.

NON-SPECIALIST SCIENCE IN THE SIXTH FORM*

By W. LLOWARCH, M.A.

(*Institute of Education, University of London*)

When I was invited to talk to you about the place of physics in the school curriculum I protested that this was much too wide a subject for a brief discourse and asked if I might, instead, deal with a special aspect which has interested me for some years now. My diffidence over tackling the wider issues has had one fortunate result, for it led to Dr. Barton being persuaded to address us and he has shown how much can be said to illuminate the general subject in the course of a short talk.†

The special problem I wish to consider is that of presenting science to the Sixth Formers who are specializing in other subjects such as classics, history, modern languages, English, or geography and economics. The majority of us here to-day follow our chosen profession of physics by *teaching* the subject. In schools, I fear, many are apt to cherish most their work with the Sixth Form specialists. Advertisements of vacant posts emphasize that scholarship work will be available and in some schools the major effort throughout the Science Department is geared to the production of successful University Scholarship candidates. Personally I think that the work we do with those who are never going to specialize in science is of great importance, particularly in the case of the bright, intelligent specialists in classics, history and languages who may become our future administrators. At this point, for our future guidance in planning courses, we might make a note of two problems to be solved. One is actual ignorance of scientific facts and laws ; the other is the tendency for these non-scientists to despise scientists and their work—and in referring to its as a *tendency* I am, perhaps, being too polite.

We here are primarily interested in physics, but I would remind any who are Heads of Departments in schools that they have to plan a *science* course. The problem of encouraging respect for our subject is, I feel, best solved by handing over the work to the tip-top specialists—people who are not merely *teachers* of physics, chemistry, biology, but who live for their subject. We must make these pupils realize that our attitude towards it is that of the artist towards his painting and the musician to his music, and bring into the course topics which will emphasize this aspect of the work of the great scientists. Just as these

* A lecture given to the Institute's Education Group at the Institute's House on April 15, 1955.

† *Bulletin*, July, 1955.

boys will consider us half-educated if we cannot join intelligently in a conversation on architecture, sculpture or the drama, or cannot justify our like or dislike when confronted with a painting or musical composition, so we must try to make them realize that, apart from its obvious utilitarian value, there are aspects of the study of science of which any intelligent person should be aware.

At Stowe I had to handle, each year, about 50 boys. The best brains were usually found among the classicists and historians and these I put together to make a group of fifteen to twenty. Modern languages and English specialists provided a compatible combination of similar size and " economic geographers " formed a group by themselves. Each set had one term with the biology specialist, one term with the senior chemist and one with me for physics. Each of us put a good deal of effort into planning a one term course which was then given three times in the year. The biologist spent a large part of the time on heredity and evolution. Chemistry, I find, provides the toughest problem, for it is difficult to get far without using chemical formulae and equations and these call for a concentrated effort on the part of the audience. My chemical colleague gave a great deal of his time to the study of raw materials, their sources, extraction and applications, and made much use of films such as those on the copper mines in Rhodesia. In this connexion he emphasized the economic aspects and the impact of the development on the lives of the native tribes.

But we must now turn to our main interest to-day—the physics course. Before putting forward my views on the content of this course may I give two examples of how not to do it At one of our better known Public Schools a new, progressive Headmaster asked the Senior Science Master to organize such courses in the Sixth Form. He handed over the physics to a young colleague, but laid down the law as to the content of the course. They must, he said, be taught the principles, and among other things be made to realize the importance of measurement. So the victim found himself expected to begin by instructing these lively and critical young men in the use of the balance and the methods for determining such physical constants as the specific gravity of an irregular solid soluble in water.

My second example comes from one of my students at the Institute of Education. Hearing that such a course was given in the Secondary Grammar School where he was practising he asked permission to observe one of the lessons. Entering the classroom he found a Leclanché cell on the demonstration bench and sat there for three quarters of an hour while the master tried to interest his audience in the more subtle aspects of its chemistry and physics. When this student asked me

if that was the sort of thing required in such courses I was pleased to note that his question was merely rhetorical.

As I have already suggested, the two major aims must be firstly to impart scientific information and secondly to attempt to convey some idea of scientific method, its achievements and limitations, and the attitude of the scientist towards his work. Personally I regard the second aim as the more important of the two. It cannot, of course, be achieved in vacuo, so to speak, i.e. without making use of facts and applications of science, but whatever is attempted under the first heading should be subservient to the latter aim. Moreover—if, as is probably the case, time is limited to one or two periods per week, one cannot cover much ground in even a single branch of physics, but one can illustrate most aspects of what we might call the background of physics.

I would now like to consider the various factors which may determine the extent and content of the physics course, and as I deal with each one I will refer to the particular conditions existing at Stowe. Take, first, the amount of time available. The scientist is expected to balance his specialist studies, of between twenty and twenty-four periods per week, say, with two or three for English, two or three for some modern language, and perhaps one for current affairs. We shall, I fear, be optimistic if we claim that the English or classics specialist should devote a quarter of his time to the study of science. In pre-war days at Stowe we ran courses for the Upper School non-scientists on a budget of two periods per week. The advent of the G.C.E. examination, with its absurd age-limit, meant that newcomers to the Upper School had still to keep up essential " O " level subjects, and the science courses had to be sacrificed. When the age limit was removed the courses were revived, but, for various reasons, we had to be satisfied with one period per week for a start. For the benefit of those who have not yet been given the opportunity to run such courses, but think that they might be able to get one period per week as the thin edge of the wedge, I hope to show later how much can be achieved with this very meagre allowance.

Next we must consider the previous knowledge of the pupils concerned. I imagine that in a Secondary Grammar School, with entry at eleven plus one could count on all having done a fairly uniform course of General Science type for two or three years at least. In a Public School it is different. Boys enter three times a year from Preparatory Schools where they may have done little or no science. When they come to us for these courses in the Upper School some may, possibly, have done no science at all, some may have had a smattering before the " O " level part of the examination absorbed too much

of their time, while a few may have taken General Science or even Physics and Chemistry at this level. Those in the third category considered that they had "done science" and need not attend the Upper School courses. We were able to convince their Tutors that these "O" level courses provided just the kind of factual basis we required for building up a really stimulating treatment of science in the Upper School and that we would be only too pleased if all had had such a foundation. The extent of their previous knowledge will, of course, govern the division of these boys into sets.

Thirdly, and very important, come the interests and tastes of the specialist who is to give the course. Provided that he can avoid riding a hobby horse to death and can remember that he is not training candidates for the "A" level Physics Stakes he is most likely to impart enthusiasm if he is dealing with topics of which he has made a special study. These non-specialist courses provide opportunity for airing one's knowledge of astronomy, modern physics, history of science, meteorology, geology and many other topics which find little or no place in the "A" level specialist syllabus. Thus the teacher himself gets a kind of refresher course.

I feel that much of the work should be presented experimentally, in the form of demonstration lectures, and we must therefore be governed by the resources of the school laboratory and our own ingenuity in devising simple apparatus and experiments.

One final problem remains. Should one develop a continuous and connected course for the term or give a series of independent lectures dealing with isolated topics. When our allowance was two periods per week I favoured the first method and gave, for example, a course on astronomy, tracing the development of the theory of gravitation and our knowledge of the solar system, theories of the origin of the solar system, speculations as to the possibility of life on other planets and the existence of other planetary systems, the size of the universe, problems of cosmology, and so on. The chief difficulty, I find, in the continuous course system is that of maintaining the interest of all members of the class all the time. If the allowance is only one period per week it is almost impossible for some of them to remember what went on in the previous lesson. Astronomy certainly has the advantage that almost everyone is interested in it and it provides a means of introducing so many branches of physics—mechanics, optics, spectroscopy, radio, and links with chemistry and biology. Again—a term may be devoted to the development of the wave and corpuscular theories of light, the spectrum, radio, quantum theory, but this is not, I find of such general interest and requires a more concentrated effort which these boys are not always able to produce. Similarly, the study of the growth of

modern physics, atomic structure and atomic energy also covers a wide field but demands a degree of co-operation and mental effort which are not always forthcoming.

Some time ago the Classical Tutor at Stowe suggested to me that it might be worth while trying a series of lectures on isolated topics. With a sufficiently wide variety one is almost certain to capture the interest of some of the audience each time and perhaps stimulate them to read more widely for themselves. It is much easier, when following this scheme, to ensure that one deals with all those points which one regards as of general importance. When we were cut down to one period per week I decided to give this method a trial, and after three years' experience of it I have come to the conclusion that it is the most satisfactory. The conclusion is based on my own impression of the attitude of the set, and on reports from other tutors who have discussed my course frankly with their pupils. Even with two periods a week I would adopt it, using some of the extra time for more class discussion than is possible with the single period. With a still more liberal allowance of time I would favour a combination of the two schemes, starting with a varied selection of single lectures to arouse interest and give me the " feel " of the class, and then developing topics which would last for two or three weeks.

I would like to conclude by putting forward for your consideration some important points which should be covered in any course and will illustrate them by describing briefly the lectures which I gave last year at Stowe. I would not claim that the list is exhaustive or the illustrations the best for their purpose. The latter were drawn from branches of physics which I find especially interesting or were topics which I knew would interest the particular sets I was dealing with.

Firstly, there are several scientific principles which should be brought to the attention of the layman, whether he is particularly interested in them or not. In physics we have the principle of the conservation of energy and the importance of not squandering our natural resources. To emphasize this point I started the course with a lecture on " Perpetual Motion," a title which seemed to catch the attention even of those who had sought refuge in the back benches. I was fortunate in having a copy of a film strip made privately for Dr. Tricker (of the Ministry of Education) which contained pictures of most of the historic attempts to achieve perpetual motion. It also gave tables of data on the efficiency of various types of engine, power stations, a gas ring, a hot plate and an immersion heater, details of schemes for utilizing waste heat from power stations and the extraction of heat from cold sources by heat pumps.

Then I have met so many people who think that scientists are hard-headed men, dealing only with brute facts and convinced that their opinions on all subjects are the last word, that I tried to give some idea of what a scientific theory is—how it is built up and used. Two examples which illustrate this admirably are the development of the theory of gravitation and the rivalry between the wave and corpuscular theories of light. Each of these requires at least two sessions. The former can be traced from early Greek speculations up to the time of Newton in one lecture, followed by a second dealing with the subsequent developments such as the discovery of Neptune and Pluto and some idea of the new point of view introduced by Einstein. The work on optics provides some elegant demonstration experiments. The fact that, knowing it to be imperfect, we still use Newton's law of gravitation, and Bragg's statement that we can use the wave theory on Monday, Wednesday and Friday and the corpuscular on Tuesday, Thursday and Saturday emphasize the idea that a scientific theory is a policy rather than a dogma.

Thirdly, I like to present the idea that the pure scientist does his work to satisfy his own curiosity about Nature and often with no thought for its possible applications. This, of course, leads to discussion on the responsibility of the scientist for the effects of such applications when they are made by others. The development of the electromagnetic theory of light from Faraday's ideas on lines of force, through Clerk Maxwell to Hertz, and the subsequent application to wireless telegraphy and telephony which, for good or ill, is having a considerable effect on our lives, can be covered in one lecture, including demonstrations of experiments on 20 cm. waves from a spark transmitter with a crystal detector and galvanometer connected to the receiving aerial. Atomic energy provides a more controversial example of the question of responsibility.

Nowadays, of course, not much research is done by individuals working singly in small, makeshift laboratories. More often it is done on an engineering scale, by teams of workers, and involves large expenditure of what must, ultimately, be public money. It is, therefore, presumably, of interest to the future taxpayer and we may have to convince him of the value of the work done. The construction of the radar telescope at Jodrell Bank, or the launching of balloons to carry scientific apparatus into the stratosphere and employment of armies of assistants to search for interesting events in photographic emulsions will serve to illustrate this point. Again, some of our pupils may eventually hold responsible positions on the administrative side of a large industrial organization and may have to decide whether or not

to let a research worker have his head and follow up some line which has no obvious immediate application.

They might, in connexion with their future careers or hobbies, have to rely on expert evidence in scientific matters and should be aware that such help is available and be able to appreciate its limitations. This I illustrated in the field of archeology by describing to them the recent work on the dating of Stonehenge by the carbon-14 method. A simple Geiger counter was constructed from a flashing neon lamp circuit and used to illustrate the difficulties arising from background count when a weak source is being measured.

That some acquaintance with scientific principles may be useful in everyday life was illustrated by two lectures. One on the tides began with an outline of the elementary theory, indicated the way in which local conditions may cause complications and concluded with a discussion of the problems involved in harnessing the energy of the tides. This, of course, provided a link with the first lecture on energy. The other lecture explained the relation between the radio waves and the sound which they carry. A double beam oscillograph was used to display the B.B.C. modulated carrier and the sound waveform. The limitations imposed on sound quality and intensity range and the number of stations in a given band seemed to be understood by the majority. A knowledge of these facts might enable one to be more critical of sales talk when purchasing a new receiver and the necessity for international conferences to allocate space in the aether can be appreciated.

An example of science being applied in industry should be included. The development of modern incandescent and fluorescent lighting serves to show the advantage of the application of scientific principles over trial and error methods and gives opportunity for elegant demonstrations again.

The rapid advance in scientific theory which follows the development of a new scientific instrument deserves emphasis and may be illustrated by the Wilson Cloud Chamber. Several forms have been described which may be constructed in the school laboratory and the production of tracks is a constant source of wonder and delight to the layman. One member of a non-specialist set was so thrilled by it that he asked to be allowed to demonstrate it in the annual science exhibition on Speech Day.

Finally, of course, one may invite the pupils to suggest topics, and give special lectures which will interest members of a particular set. Thus, musicians will be interested in a talk, with demonstrations, on the instruments of the orchestra and will be delighted to play to the

microphone and have the wave forms displayed on the oscillograph. This may be followed up by a lecture on the limitations of the various recording systems.

And now I must conclude on a note of dissatisfaction. So often, at the end of one of these termly courses, I have felt that I have given these non-scientists something which should be included in the specialist courses—emphasis on the scientific method, a fairly detailed treatment of some aspects of the history of science, sometimes a discussion of problems in philosophy, ethics, economics—but they don't ask questions on these matters in the "A" level examinations and somehow so much that would make our subject, physics, come more alive, gets crowded out.

THE APPLICATION OF THERMODYNAMICS TO INDUSTRY*

By G. G. HASELDEN, Ph.D.
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Since thermodynamics has to do with all industrial operations in which energy transfer is occurring there is a sense in which the application of thermodynamics in industry is universal. However it will be the aim of this lecture to pick out instances in which thermodynamic principles have been consciously applied to important industrial operations and significant advances or economies in operation have resulted.

The function of applied thermodynamics can be considered under three headings :

(i) It provides an aid to the understanding of a given process ;
(ii) it enables the efficiency of a given process to be exactly stated ;
(iii) it provides a system of correlation for the properties of pure substances taking part in the process and for solutions of these substances at equilibrium.

The role of these three functions will be illustrated by a number of examples.

POWER GENERATION

In the field of heat engines the concepts of enthalpy and entropy are the stock-in-trade of the engineer, and future developments depend to no small extent on the provision of more accurate and extensive charts of these properties. Where heat engines are used for purposes of propulsion the thermodynamic problems of efficiency often become secondary to consideration of bulk and flexibility of output, but in the field of large scale power generation efficiency is of prime importance. Here the application of the second law has given the power engineer a clear understanding of the ways in which existing processes must be modified in order to give increased power output from unit weight of fuel. This knowledge has made him turn his mind not only to processes operating at higher temperatures but also to those in which the pattern of heat liberation from the fuel is matched by the pattern of heat absorption of the engine. Thus irreversibility results if the heat available in the hot gaseous products of combustion cooling through a temperature range is absorbed by water boiling at constant temperature. Hence the use of steam superheaters which enable heat to be usefully employed at higher temperatures, or better still the boiler is operated at a super-critical pressure and the latent heat jump in the

* A lecture given to the Institute's Education Group at the Institute's House on April 14, 1955.

heat acceptance curve is avoided. Gas turbines offer advantages in this direction because the turbine effectively utilizes heat over a range of temperature.

Thermodynamics has played an important part in the development of the gas turbine not only in determining the optimum cycle for power generation but also in the calculation of the combustion process and flame temperature.

The knowledge which thermodynamics gives of the efficiency of even the best of present generation cycles provides the spur to endeavour to recover a much larger proportion of the free energy of the fuel. Thus much thought and ingenuity is being devoted to the development of fuel cells in which, by electrolytic processes, the free energy of the fuel can be directly withdrawn as electrical energy. Whilst the problems here are formidable considerable success has already been achieved for cells consuming gaseous fuels under pressure.(1)

In the field of nuclear power thermodynamics also affords useful insight. If power production is to occur through the intermediary of heat liberation then not only will the heat engine be required to accept heat at the highest possible temperature but it will also be required to do it at near constant temperature. This requirement confronts the engineer with a relatively new problem. Here again thermodynamics shows the need for a process for direct nuclear to electrical power conversion.

HEAT PUMPS

The concept of heat pumping follows immediately from the second law. Its direct application by which electrical energy consumed in an electric motor is used to transfer a quantity of heat, taken in at the ambient temperature of the atmosphere, ground or nearby river, to a temperature at which it can usefully be employed for house heating, does not at present appear to be economic for the average conditions encountered in this country. Theoretically, for average temperature values encountered, one can expect about five units of heat for each unit of electricity, but practically attained efficiencies limit this performance to 2·5 to 3·0. Against this, however, is the fact that the heat output falls off rapidly as the temperature of the heat source diminishes, which is a most undesirable operating characteristic for winter comfort. Also the capital cost of the installation as compared with a fuel-burning installation of equivalent output is extremely high. Thus the use of heat pumps at the present time is restricted to districts where a source of low grade heat is readily available or where the summer climate justifies the installation of the same equipment to operate in reverse for air conditioning.

In the chemical industry there are a number of instances in which heat pumps can very profitably be installed and where the same limitations do not apply. A large fraction of all chemical plant is taken up with heating and cooling materials and if these duties can be co-ordinated by heat pumps then substantial savings are possible, especially in areas where fuel is expensive. Particularly favourable conditions for their use arise in processes such as the evaporation of sugar solutions where the extracted heat can be raised in temperature and fed back into the same unit. Thus the steam generated from a boiling sugar solution need only be compressed (by a reciprocating or turbo-compressor) by a small amount to bring its condensation temperature above the boiling point of the solution, then it can be recondensed in heat exchange with more solution and the process perpetuated. If the compressor is driven by a steam turbine supplied from a separate source then 1 lb. of this steam can be used to evaporate as much as 8 lbs. of water from the solution. If the economic situation does not justify the capital cost of the compressor then a steam ejector may be employed for a similar purpose but at lower efficiency. Only 2 to 3 lbs. of evaporation per lb. of supplied steam will be obtained in this case.

It should be noted that the use of a steam ejector results in a heat-operated heat-pump. The absorption machine, which will be mentioned in connection with refrigeration, can also be used in this way. In fact, as will be referred to later, one can have a cold-operated heat-pump.

REFRIGERATION

The uses of thermodynamics in refrigeration are extensive. Not only is the choice of cycle and refrigerant largely settled from thermodynamic considerations but also the compression process is analysed from this standpoint. The vapour compression type of refrigerator when performing a constant temperature duty at around the ice-point already achieves a thermodynamic efficiency in the region of 80%, so there is little scope for further power saving. The main fields for development are therefore concerned with low refrigeration temperatures or heat-operated refrigerators.

At low temperatures the energy required to remove a unit of heat becomes large and the achievement of high efficiency is vital. The Heylandt cycle, which is used in an adapted form for the industrial production of liquid oxygen furnishes a good example of the contribution of thermodynamics in this field. The Heylandt cycle (Fig. 1) operates efficiently because it is closely related to the properties of the working fluid. An expansion engine, having near reversible action, is used in a pressure temperature zone in which the fluid has approximately

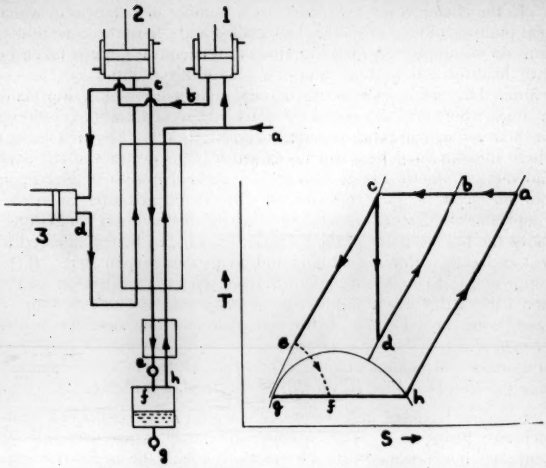

FIG. 1. *Heylandt Liquefier flowsheet and Temperature-Entropy Diagram.*
1. Compressor up to 20 atm. 2. Compressor for further raising pressure to 200 atm. 3. Expansion engine 200 to 20 atm.

perfect gas properties, thus giving a large cooling action and power recovery. The cooling so produced is well matched to the heat liberation characteristics of a high pressure throttle valve liquefaction cycle, so that the high pressure gas is cooled to a low temperature before throttling. Thus the valve expansion takes place in a zone in which the departure of the gas from ideality is a maximum, and the resultant cooling is again large.

The heat-operated absorption refrigerator[2] finds a considerable range of application industrially in addition to its domestic use. A number of large ammonia absorption machines have recently been installed at chemical plants for providing cooling at about $-30°$ C, whilst a range of machines using the water-lithium bromide system is being employed for the air conditioning of large buildings. It is conceivable that solar radiation could be used as the driving force for this type of air-conditioner. The thermodynamic basis governing the operation of these machines is now well understood, which allows their advantages to be fully exploited,

A novel application of the absorption refrigerator principle was described many years ago by Maiuri[3] in a device called the cold multiplier (Fig. 2). This is a form of domestic refrigerator cooled by solid carbon dioxide in which the cooling provided in the cabinet is nearly twice that provided by the evaporation of the solid refrigerant, the excess heat being given up to the room. Whilst up to the present this device has not found wide application it is interesting to consider that in an adapted form this apparatus could employ the cold of a winter night to extract heat from the ground and present it at a higher temperature for warming a house, without the expenditure of any fuel.

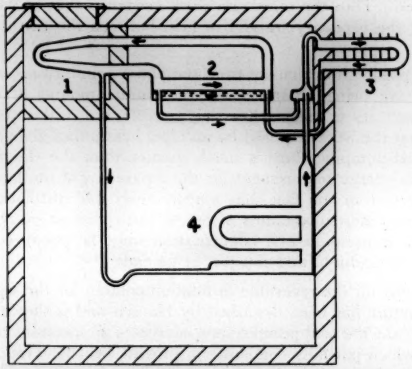

FIG. 2. *Simplified layout of Maiuri's cold multiplier, condenser cooled by solid carbon dioxide.*

1. Condenser in which ammonia is condensed from the hydrogen stream.
2. Desorber, ammonia evaporating from strong solution into hydrogen.
3. Absorber, rejecting heat to the atmosphere. 4. Evaporator.

APPLICATIONS OF THERMODYNAMICS TO THE CHEMICAL INDUSTRY

The scope of chemical thermodynamics is very wide and the contribution it has made to industrial chemistry is far reaching. This field is well covered in text books of chemical thermodynamics. It is not generally realized, however, that thermodynamics contributes to the understanding and development of the many separation processes

basically physical in character used in the chemical industry. The process of distillation may be cited as an example.

A simple distillation column for continuously separating a feed solution or vapour mixture into two different fractions consists of a tower containing some contacting device for bringing liquid and vapour into close proximity, a reboiler in which external heat is used to vaporize part of the liquid collecting at the base of the column, and a condenser for returning part of the vapour leaving the top of the column as liquid reflux. The energy requirement of the distillation process is therefore the addition of heat at the appropriate temperature in the reboiler and the extraction of heat at a lower temperature in the condenser. Thus the minimum work needed is that of a heat pump effecting the necessary transfer of heat between the two temperature levels.

It is possible to calculate from the phase equilibrium properties of the mixture being separated the minimum amounts of reboil and reflux necessary to make separation possible, but in this case it is also found that the work required by an ideal heat pump giving this minimum heat-pumping duty is much greater than the thermodynamic minimum energy requirement for the separation of the feed mixture. This arises from the fact that a truly reversible distillation column must have different amounts of reboil and reflux at every level and therefore evaporation and condensation must be produced at many levels in the column and not just at its ends.

A model for the reversible distillation column for the separation of a gas mixture has been described by Hausen and is shown in Fig. 3. In this model the heat pump system consists of an incoming compressed vapour which partially condenses to provide heat for evaporating the bottom product and is then further condensed in successive stages at diminishing pressures in the lower half of the column. Between each heat liberation stage the residual vapour is expanded in an engine and some work recovered. Above the level of the column feed the liquid produced in the heat-pump cycle is successively evaporated at diminishing pressures, further amounts of work being recovered from inter-stage expansion engines. The resulting vapour is adiabatically compressed (to raise its temperature to that of the incoming vapour) before being taken through the heat exchanger to the main compressor. The sum of the work terms for the various compressors and expanders for this system shows a power requirement equal to the minimum energy of separation.

When the efficiency of a large modern plant for distilling crude petroleum into seven fractions was analysed it was found that although

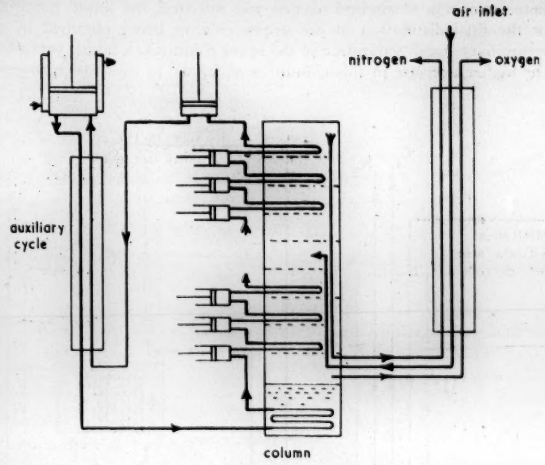

FIG. 3. *Hausen's Reversible Column for the Separation of Air by Distillation.*

only 1·5% of the calorific value of the feed was used as fuel to provide reboil and although the furnaces had a thermal efficiency in excess of 70% the thermodynamic efficiency of the plant was only 12%. Of course the final design criterion for any piece of plant is economic and the present balance between fuel and investment costs may partially justify a low efficiency, though it is not necessarily the case that increased efficiency required a larger and more costly plant.

A further example of a distillation plant in which a rigorous thermodynamic analysis has been applied, and has already resulted in great economies in manufacturing cost, is the production of oxygen by the distillation of liquid air. The classical type of plant for this separation as developed by Linde is shown in Fig. 4.

The inlet air is compressed to 60 atmospheres and cooled in a heat exchanger before being condensed in the reboiler of a Linde double column. The double column is a device for obtaining virtually com-

plete separation of air into oxygen and nitrogen, the liquid required for the final distillation in the upper column being obtained by a preliminary rough separation in the lower column at a higher pressure. The higher pressure in this column is necessary to condense nitrogen

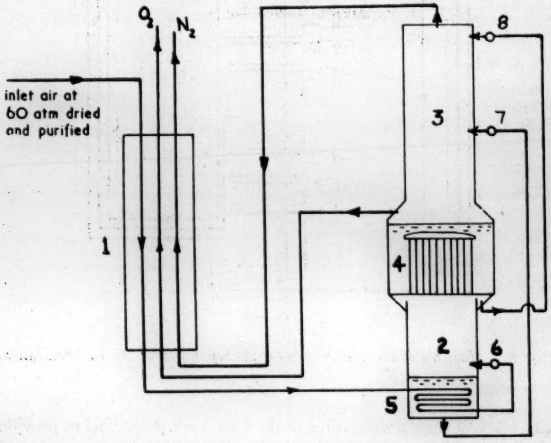

FIG. 4. *Classical Type Air Separation Plant Employing the Linde Double Column.*

1. Heat Exchanger. 2. Lower high pressure column. 3. Upper low pressure column. 4. Condenser-evaporator. 5. Reboiler. 6. Main Expansion valve. 7. Rich liquid expansion valve. 8. Liquid nitrogen reflex expansion valve.

(of lower boiling point) against boiling liquid oxygen. The gaseous oxygen and nitrogen products are withdrawn through the heat exchanger thus warming them to near atmospheric temperature. For this plant Ruhemann(4) has calculated the entropy increases occurring in each component as follows :—

	Entropy increase (cal/°C./mol. O_2)
Lower column	3·09
Upper column	9·70
Heat exchanger	9.10
Main expansion valve	3·68
Nitrogen expansion valve	0·96
Rich air expansion valve	1·60
Reboiler	11·40
Condenser/evaporator	0·20
Entropy of mixing for air	5·02
	44·75 ($= \Delta S$)

If heat is rejected to cooling water at 288° K ($= T_0$) then the work which must be performed to meet the irreversibilities of the plant and to supply the work of separation $W = T_0 \Delta S = 288 \times 44{\cdot}75$

$= 12{,}880$ cal./mol. O_2

$= 0{\cdot}619$ kWh/m^3 O_2

Allowing a practical compressor efficiency of 60% the actual power consumption $= 1.03$ kWh/m^3 O_2, which agrees well with measured values.

This type of analysis immediately shows the points in the process chiefly responsible for power wastage. The ways in which many of these irreversibilities can then be eliminated or reduced can be seen from the flowsheet of a modern Linde-Frankl type of air separation plant (Fig. 5) for the production of 95% oxygen on the scale of more than 100 tons per day.

The cold production of the plant is now achieved by a turbine which, operating at near isentropic performance, provides all the necessary cooling with an inlet air pressure of only 5·5 atmospheres instead of 60 atmospheres. The reboiler is eliminated and regenerators are used in place of the heat exchanger. The larger surface area of the regenerators allows the outcoming products to be warmed to within about 2° C of the incoming compressed air temperature, whilst the low inlet pressure together with the turbine side-stream enables the temperature head at the cold end of the regenerators also to be very small. Thus the entropy gain associated with the heat exchanger is greatly reduced. Even the irreversibility of the column system is reduced somewhat by injecting the turbine effluent directly into the upper

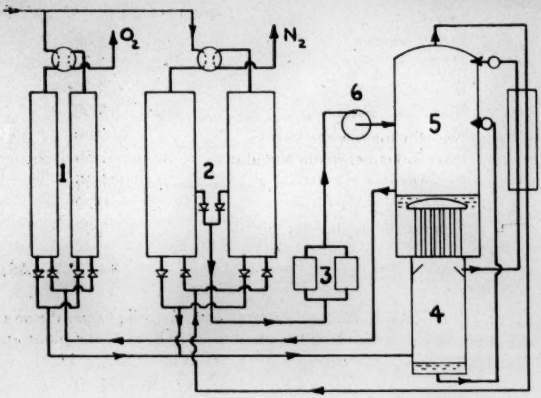

FIG. 5. *Modern Linde-Frankl Tonnage Oxygen Plant Flowsheet.*

1. Oxygen Regenerators. 2. Nitrogen Regenerators. 3. Carbon dioxide absorbers. 4. Lower column. 5. Upper column. 6. Expansion turbine

column, thus reducing the reflux ratio there. The influence of all these changes is to reduce the actual power consumption from 1·0 to about 0·4 kWh/m^3 O_2. This power saving, together with the reduced capital cost of a plant handling only moderate pressures, has made possible the use of oxygen on a greatly increased scale in a number of chemical and metallurgical processes.

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THE TEACHING OF THERMODYNAMICS*

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The average standard of teaching in any subject, whether arts or science, is low—for the obvious reason that the standard of mind of the average teacher is far below the standard of the original and creative minds which formed the material of his subject. It will be understood that I am referring to average teaching and not to those happy cases where the originality and creativity of the mind is expressed in its power of teaching.

Now thermodynamics is the worst taught branch of physics precisely because its concepts have required the most subtle creative and generalizing minds for their creation. The range and significance of these concepts is, quite frankly, beyond the grasp of the average physicist or engineer and—*a fortiori*—the average teacher of the subject. There is however a double tragedy in the case of thermodynamics as compared with many other subjects. In the case of advanced nuclear theory, for example, it possibly does not matter if the material is badly taught, because the calibre of the learner's mind is likely to be such as will rise above the deficiencies of the teaching. It is a subject which by its nature is likely to contact and concern only a relatively small number of brighter brains. But thermodynamics has to be taught to all sorts of grades of people ; the result is that the bad teaching of thermodynamics has far more serious and widespread consequences than that of most other subjects.

The bad teaching to which I refer is in part the responsibility of writers of text books, who have failed so far to produce a satisfactory agreed statement of this universally applicable subject. Let me give you one major example of this failure, and point out its serious significance.

One would have thought that after about 100 years of recognition of the equivalence of heat and work the presentation of thermodynamics would be as the science of a unified energy. There should not be in any modern text book or teaching course the intrusive and quite unnecessary symbol " J." The transformation from ft. lbs. to British thermal units or from ergs to watt hours or to calories should be regarded as self-evidently just the same as transformation of units of length from miles to feet or feet to metres, etc. Yet teachers and text-book authors persist and most text-books now published still contain " J."

* An opening contribution to a discussion held at the Institute's Group on April 14, 1955.

Now some may be tempted to dismiss that as unimportant. I am convinced that it is of considerable importance because it perpetuates a basic falseness of approach which permits an equally basic wrongness in our attitude to things. It is because of this wrong attitude that we persist in using the term *efficiency* when talking about heat engine cycles. The real fault is a failure to distinguish clearly between two forms of energy. Instead of striving for a clear conceptual distinction between ordered energy and dis-ordered energy the conversion symbol "J" is used, and, by appearing to deal with the matter, this has effectually blocked proper consideration in the mind of the student. He should see a heat engine cycle as a means whereby a portion of dis-ordered energy becomes ordered, and he should realize the significance of the temperature ratio in controlling and limiting the proportion which can become ordered. Instead of this he thinks of heat and work as entirely different, yet magically connected by a formula involving "J." He is convinced he knows all about this, and he therefore thinks of the temperature ratio as an efficiency of conversion, *with the accompanying implication that whatever has not been converted has been lost*, in the same sense as he knows energy to be lost and dissipated in, say, a gear train.

Since practically every engineer and physicist in the last 100 years has learnt in his youth this mistaken attitude of efficiency, it is not surprising that modern power station turbine cycles nearly all throw 70% of their energy into rivers, the sea, or the atmosphere through cooling towers. Only in recent years has there been a slight dawning of the fact that if the so-called efficiency had been made a little less, the energy now thrown to waste would have been all valuable for purposes for which energy in the dis-ordered form is absolutely necessary. I believe that if the correct concept of a proportioning ratio between ordered and dis-ordered energy had been effectively clarified and effectively taught, say from 1900 onwards, we should have been in a far stronger position and have required far less fuel than we do to-day. The tragedy now is that so much capital has been sunk in high vacuum condensing stations that it is practically impossible now to make a major change in practice and to incur the large capital expenditure which back pressure turbines would require.

That is one major example. Let me give you a very minor one, although this may be even more strongly indicative of the bad teaching which can plague this subject. Not so long ago I had the occasion to look over the work notes of one of my junior staff, who was then attending a well known and well reputed Technical Institution. In his lecture notes which were dealing with some formula derivation in thermodynamics I was puzzled by the number 2 which kept cropping up frequently, and for which, in my innocence, I could not account.

I considered that it would become me better to admit my ignorance and learn from this junior member rather than simply pretend that all was in order, and that I knew what the notes were about. So I asked him. I received the easy and completely confident reply, " Oh, that is the gas constant per mole." I asked him why he did not write it as " R," and was informed with a pitying look that its value was 1.98, and that that was near enough 2 for all sensible people who naturally wanted to avoid the use of mathematics wherever possible. I tried to explain to him that to write the symbol 2 instead of 1.98 was just as much mathematics in the sense in which he was using the word as to write the symbol " R," but that in addition writing 2 carried with it the serious risk that he would forget the dimensions it had, or that it ever had any, and moreover that a stupid person like myself might very well be tempted to forget what it was and cancel it out if in the treatment there arose an opportunity of cancelling it with another number. Some months later my young colleague was found to have made an error in quite an important calculation, and I was sorry, but not surprised, to find that the error had arisen precisely from the use of 2 in this equation when he was working in some entirely different units. Still one more example, this time not of the difficulties of a junior, but of the convictions of a quite eminent and responsible engineer. The subject under discussion was cavitation, i.e. the formation and subsequent collapse of vapour bubbles in water, such as occurs in the neighbourhood of a ship's screw. The inrush of water when the bubble collapses sets up a severe hammer shock which can cause destruction of the adjacent metal. A theory had been put forward in which the effect of the latent heat release of the condensing vapour in the centre of the bubble in slowing down the collapse of the bubble was discussed. This theory was assailed by the quite eminent person referred to on the grounds that it contradicted the second law of thermodynamics because it envisaged scattered high temperature points arising within the fluid with subsequent conduction from there. This gentleman had completely failed to grasp the fact that the second law applies only when you include all the elements of your universe, and that it ceases to apply whenever you consider a limited portion acted on by another portion which you exclude from your considerations. In the particular case under discussion the phenomena occur because of the action of a machine, i.e. the propeller which is causing a cycle of high and low pressure on the water. It is true that the second law as normally taught is provided with the qualification phrase " of itself " or in the absence of the machine, but this statement is not clear enough nor comprehensive enough to last for all the exigencies which an engineer is going to meet in his lifetime.

Well, so much for examples of the results of bad teaching. Is there any satisfactory way in which we could define good teaching of this subject, other than the merely negative way that it should, of course, avoid such errors as I have illustrated. In other words, can I make any constructive suggestions instead of destructive criticism. I have already given two slight indications of what I feel would be constructively useful. The first was that as a general principle thermodynamics should be taught as the science of unified energy. The second was that the two different aspects which are commonly known as heat and work should be referred to in these terms only at the elementary and introductory stages of the subject, as, for example, at school level. In a university or technical college course these terms would be early abandoned in favour of the carefully expressed concepts of dis-ordered and ordered energy. As a consequence of this, the idea of conversion from one form to the other would be abandoned in favour of the concept of a division ratio or proportioning ratio.

The next point I would like to make is rather more complex. You are, of course, aware that in teaching thermodynamics there are necessarily many parts or items in the subject which must be taught as mere technicalities, such as, for example, the various heat engine cycles, the specific thermodynamical relations, the definitions of the thermodynamic functions, the examples of the use of these functions and relations in application to physical chemistry, reaction energies, thermo-electric circuits, electric cell potentials, and so on. These must all be gone through, and there is no satisfactory substitute for working out examples. But I would suggest that the student should be made to feel, much more than he is normally made to feel to-day, the sense and atmosphere of thermodynamics. Here is a subject which should do more than merely train a man—it should *educate* him. In other parts of this conference you are to hear or have discussed the question of physics as a means of education, i.e. as a contribution to the formation of a man's internal culture. Now with all respect to our science, I doubt if for the most part it really can contribute much which is really educational in that sense. Indeed, with the absurd emphasis on experimentation and laboratory skill which too often accompanies it, it does not nowadays even provide normally as good a grounding in reasoning and ratiocination as does the study of classical or other syntax. This is said not to despise laboratory and experimental skill but to point out that they are not *educative*, except in the same sense and to no higher extent than are the skills of the craftsman worker, the joiner, the cabinet maker, the plumber, the welder. But with thermodynamics we do have an opportunity of education which should be fully grasped. In this one branch of physics far more than in any other we

have the opportunity of presenting to a student not only a foundation on which he can stand but also a vista and landscape which he can survey, and of which he should be able to feel " this is a world ; this hangs together ; this has form and location ; this makes sense and feels whole." It is true, as Prof. Vick in his account of the organization of the University College of North Staffordshire has indicated, that you cannot educate a man by physics alone, not even with thermodynamics, but I would submit the thesis that where time for occupation with other subjects is limited, then thermodynamics is the most educative influence which can be brought to bear. Moreover, even when there is time for the inclusion of some of the liberal arts then thermodynamics provides the most satisfactory bridge between the factual teaching of physics and the thoughful teaching of other subjects.

In conclusion I would like to answer one query which may be in your minds. Why should I, with an industrial point of view, lay so much emphasis on atmosphere or educative aspects of thermodynamics ? You may feel that I should stress much more its technicalities and its formulation. But I have already indicated that I consider these very important and that it is appropriate and necessary that they be taught properly, and I have given some examples. The reason why I must nevertheless emphasise the more general educative influence which thermodynamics should provide is because while experts in mere technicalities and technologies may be quite useful members of a restricted academic or technical college community, they are of very little value in industrial life. I do not say we cannot or do not use such people ; we obviously do use many of them, but we do find that they can neither give of their best nor be advanced to more responsible positions unless they have the flexibility of mind which a lively education alone can give.

THE TEACHING OF THERMODYNAMICS TO APPLIED PHYSICISTS*

By Professor M. W. THRING, M.A., F.Inst.P.
(*University of Sheffield*)

I think one has to start by asking the question " What do we want a graduate to be able to do with his thermodynamics ? " The first answer can be illustrated by two negative examples. One of these is that of a graduate who spends a good deal of his spare time working out ingenious perpetual motion machines ; the other is that of the inventor who produces a highly efficient power cycle in which he proposes to discharge his heat at the temperature of liquid air. A third example is the ability to criticise the proposals for converting atomic energy to electricity by means of the intermediate stages of hot gas and steam. These examples show that we want a graduate to be able to use thermodynamics not only as a language, but as an implement of thought with which he can decide the practicability of processes.

One can in fact distinguish three different objectives in the use of thermodynamics—those of the theoretical physicist, those of the chemist and those of the applied physicist. The theoretical physicist is interested in having an ordered structure of knowledge and understanding of the universe, and for him the principal aim in studying thermodynamics is that it enables him to derive relations between certain variables which correspond to the description of the equilibrium condition. For him the Carnot cycle carried out in its true perfection is the essence of thermodynamics. In fact, his study is so far practically confined to what is truly to be called " thermostatics," since it does not involve the time element. This limitation also applies to the chemist who introduces the additional complication of a chemical reaction, but is still concerned with the equilibria in such a reaction carried out infinitely slowly. The applied physicist differs from the theoretical physicist and the chemist, not in the depth to which he proposes to pursue fundamental studies, but in the fact that he is concerned with the possibility of using the results to solve practical problems. Thus for him thermodynamics is primarily a means of distinguishing between what is possible and impossible and then of telling him how near he has got to what is possible. For the applied physicist it is not sufficient to draw the PV diagram of the Carnot cycle as having intersecting curves ; it must be drawn accurately to scale, so that he can see what a very large change in pressure and volume is necessary to extract a reasonable amount of power from the cycle.

* An opening contribution to a discussion held by the Institute's Education Group on April 14, 1955.

He is, moreover, always concerned with real fluids at practicable pressures, and not with the perfect gas at a very low pressure.

These different objectives in the teaching of thermodynamics have led to very considerable deviations in the way in which it is taught by the different departments at the university, and one plea which I would put forward is that these differences in treatment should be reduced, both in order that physicists, chemists and engineers shall talk the same language and for the benefit of students of some departments, such as my own, in which they learn thermodynamics partly in each of the other departments.

PHYSICAL THINKING

I think it is very useful to define a concept which we can call "physical thinking," and to say that our object is to enable the student to use thermodynamics for his physical thinking. Physical thinking means giving a full answer to the question "What does it really mean?" If we try to analyze what is involved in physical thinking, making use of modern psychological theories of knowledge, we can conclude that it involves knowing the subject in three different ways; that is, using three kinds of knowledge which can be called the mathematical or logical, emotional or feeling, and bodily or physical. The mathematical or logical knowledge involves the construction of a set of logical concepts and the definition of the properties of these concepts, such as that the entropy of a substance is a perfect differential, and the algebraic manipulation of these concepts to produce mathematical results. This kind of knowledge is the easiest to teach or to put into a textbook, since it can be transmitted as a single series of steps. It is not, however, nearly sufficient for a full understanding of thermodynamics, because when it is applied to any real problem it always involves a series of simplifying assumptions which cannot be justified on purely logical grounds, because one has no means of checking either the sign of the terms involved or their order of magnitude, and because a purely logical argument cannot tell one in which direction to set out for the solution of a problem. The emotional or feeling side of thermodynamics is very important and is much more difficult to convey. It can be described by comparing the process with taking sides in some sporting contest. Thus each thermodynamic function has to acquire some emotional context, as for example, that a large free energy is a good thing, whereas an increase of entropy is a bad thing, before it is fully understood. Emotional thinking can give a feeling for the ultimate solution of the problem, and although it may be wrong in other respects will not make a mistake in the sign of a term in the solution. Bodily or physical knowledge is the kind of knowledge obtained from the practical handling of experimental

material ; the kind of knowledge that enables one to look at or press upon a wooden structure and decide it is not strong enough for a given purpose without any calculation. It has the advantage that it cannot get the order of magnitude of a solution wrong. A difficulty with thermodynamics from the point of view of bodily knowledge is that it is not based on one single experiment, but depends on the failure of all experiments which would contradict it if they succeeded, and on the agreement of predictions from the laws when they are attested under rather idealized conditions. Nevertheless, some approximation to bodily knowledge can be obtained by the regular use of certain diagrams, which involve the numerical representation of the appropriate properties, particularly the diagram relating free energy and absolute temperature for a series of reactions, and the entropy diagram for a working fluid, such as steam/water or carbon dioxide.

The purpose of a University lecture is to try and get all three kinds of knowledge across. The mathematical or logical knowledge is the easiest to get across, since it can be developed as a straightforward argument, but if this were the only kind of knowledge it could be transmitted by textbooks without a lecture. Emotional knowledge requires coming to the same point from several different directions, the use of emphasis and repetition and of analogy, such as that between Ohms law and the flow processes in thermodynamics. I think that one of the reasons why entropy always proves a difficult function to have concrete feeling about is that its increase is a bad thing, whereas the functions, such as free energy, whose increase is a good thing are much more readily understood by comparison, for example, with one's bank balance. It was for this reason that I introduced the function of "virtue" for the purpose of illustrating the degradation of energy during the heat transfer process across a finite temperature difference or during irreversible combustion. The use of this function readily illustrates how, from the point of view of the second law of thermodynamics, the greatest degradation of energy occurs in the boiler and not in the turbine of a power station. From the point of view of emotional knowledge the use of different symbols for the same function, as for example when the chemist uses S for entropy and the engineer uses θ, is highly undesirable because it helps to attach one's feelings always to the same symbol. For the mathematician, changing his symbols every time he works out an argument is excellent, but it is a great handicap to the development of emotional knowledge of a subject.

In conclusion, I would say that the student should learn that in a real world he can only be sure of a new result when he has arrived at the same conclusion by all three lines, that is, by the application of all three kinds of knowledge.

Woolwich Polytechnic, London, S.E.18

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G. R. Hanson,
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